

two arms of a Wheatstone bridge, in a uniform temperature bath.

#### WILLIAM ALLINGHAM.

William Allingham, for many years principal assistant in the marine branch of the Meteorological Office, died suddenly January 24, 1919, at the age of 69. His early life was spent at sea, but, owing to a disabling accident, he obtained in the early seventies a post in the Admiralty, then in 1875 he was transferred to the staff of the Meteorological Office. In addition to a practical knowledge of navigation and meteorology, Allingham was gifted with considerable literary ability. His chief works were the compilation of a Manual of Marine Meteorology, and in conjunction with Capt. Wilson-Barker, a treatise on Navigation, Practical and Theoretical.—*From Symons's Met'l Mag., Feb. 1919, p. 4.*

#### RELATION BETWEEN VEGETATIVE AND FROSTLESS PERIODS.

By JOSEPH BURTON KINCER, Meteorologist.

(Dated: Division of Agricultural Meteorology, Weather Bureau, Washington, D. C., Jan. 13, 1919.)

The two most important climatic elements with reference to plant growth are temperature and precipitation. Of these, temperature is the more effective in establishing the geographic areas within which certain plants thrive best on the one hand, or even fail to mature on the other, and it also determines the period of the year during which growth is possible.

In any study of plant growth as affected by temperature, there are two important phenomena that may be considered as constituting critical or basic points from which reckonings must be made; these are the vegetative temperature and frost. The first defines the potential period of plant growth, which is determined by the date in spring when the temperature rises sufficiently high to render active the protoplasmic content of vegetable cells, and thus produces growth, and the date in fall when it falls below this point and growth ceases. The frostless period is determined by the dates of the last killing frost in spring and the first in autumn. It is the object of this paper to study briefly the relation of these two basic periods, and their variations in length in different sections of the United States.

The average growing season as determined by frost occurrence is understood to be the number of days between the average date of last killing frost in spring and the first in autumn, but some plants are more susceptible to frost damage than others and consequently the growing season as thus defined varies in length in the same locality for different plants. This is also true for the vegetative period as determined by the amount of heat necessary to produce plant growth, considered independently of the occurrence of killing frost. It has long been known, however, that for most plants in temperate climates, the vegetative or active period begins in spring, as a general rule, when the mean daily temperature rises to 6° C. (42.8° F.), and ends in autumn when it falls below that value. These limits have been adopted for the purpose of this study of the relation of the vegetative to the frostless period.

Chart I shows the average dates in spring when the mean daily temperature rises to 43° and Chart II the dates in autumn when it falls below that value. The vegetative period, represented by the average number of days when the mean daily temperature is 43° or higher,

#### CAPTAIN MELVILLE WILLIS CAMPBELL HEPWORTH.

Apr. 27, 1849–Feb. 25, 1919.

The death of Capt. M. W. C. Hepworth, following so soon after that of Mr. Allingham, is a serious loss to the Marine Division of the Meteorological Office, of which he had been Superintendent since 1899. The Monthly Meteorological Charts of the North Atlantic and Mediterranean, as well as of the East Indian seas, were initiated during his tenure of office, and the later editions of the Barometer Manual for the Use of Seamen and the Seaman's Handbook of Meteorology were compiled under his direction and attained a large circulation. Capt. Hepworth was much interested in marine biology and in the temperature and salinity of the sea. For the many years while at sea he made a study of meteorology which prepared him for his official position.—*From Nature (London) Mar. 6, 1919, p. 8 and Symons's Met'l Mag., 1919, pp. 13–14.*

is shown for different sections of the country by Chart III. This period is not the same, of course, for each year, but varies from year to year, as does the frostless season or any other period determined by the average dates on which phenomena occur. From the Rocky Mountains westward the charts are highly generalized, owing to the great variation in the topographic features of that section of the country.

Chart I shows that the advent of the vegetative period in an average year ranges from the first of February in the northern portion of the Gulf States to May 1 in extreme upper Michigan and northern New England. Chart II indicates that this period comes to an end, on the average, in the extreme northern districts about the middle of October, but it continues till the end of the year in the South. Chart III shows that the length of the period ranges from less than 180 days in the extreme north and in the central and northern portions of the Rocky Mountain region, to 365 days in the south Atlantic and Gulf districts, and also in the central and southern Pacific coast sections. (The latest frost charts are those appearing in the frost section of the Atlas of American Agriculture, recently published.<sup>1</sup> See also "The Probable Growing Season," by William Gardner Reed, MONTHLY WEATHER REVIEW, Sept., 1916, 44, 509–512.)

The normal daily march of temperature is closely allied with the annual march in establishing the vegetative period. For example: If we assume that most vegetation is awakened from the dormant state when the daily mean temperature rises to 43°, it is evident that prior to the date on which this occurs, the temperature during the warmer portion of the day would be sufficiently high to produce growth and consequently, it would appear, that some growth actually begins before the mean temperature rises to the vegetative point (on the average, the temperature during approximately one-half of the day is higher than the daily mean). This, however, is true only in a limited degree, as will be evidenced by a careful consideration of the amplitude of the daily extremes of temperature. This amplitude varies with the moisture content of the air and its attending phenomena, with the latitude, and also with the sea-

<sup>1</sup> Advance sheets 2, pl. II, sec. 1; issued, 1918; 34 x 48 cm., 12 pp., 12 colored maps, 10 weather maps, 10 graphs. Selected bibliography. Review in M. W. R., 1918, 46:516–517.

sons, being considerably greater in the warmer portion of the year than during the colder months. During the transition season, that is the time of passing from the nonvegetative period to the vegetative period in spring, and vice versa in fall, the amplitude of the daily temperature march is quite uniform in most sections of the country, averaging about twenty degrees F. It will thus be seen that until the mean daily temperature rises to 43°, the daily minima, as a rule, fall below the freezing point, which precludes any appreciable permanent growth. The fact that the mean minimum temperature rises above the frost line (32°) coincidentally with the rise to 43° in the mean temperature probably has a more direct bearing on the significance of the latter as the vegetative value than has the fact that the temperature stays above 43° on the average for half the time during the day.

Owing to the fact that normal mean daily temperature values are available for only a limited number of stations, and do not appear in the periodical publications of the Weather Bureau, botanists frequently determine the limits of the vegetative period by considering all months with a mean temperature of 49° or higher as growing months and those with temperatures below that value as nonvegetative months.<sup>2</sup>

This assumes, of course, that when the mean monthly temperature is as high as 49° the entire month, approximately, will have a mean daily temperature of 43° or higher. The method is often unsatisfactory, however, as it is evident that by its use one degree in the mean monthly temperature (48° instead of 49°) would make a month's difference in the length of the estimated vegetative period, while there would be actually a difference of only about three days. Moreover, this relation holds good only when the temperature is near the vegetative value (from 40° to 50°) during the months of March and April in spring, and October and November in fall, when the changes in temperature are rapid. With a mean monthly temperature as low as 45° from December to February, the mean daily values usually remain above the vegetative point throughout the month, but with a mean of 45° in March or April that value is not reached until about the 10th, while in October and November with a mean monthly temperature of 45°, the mean daily temperature falls below the vegetative point about the 22d.

In computing the average vegetative period from monthly temperatures, it is preferable to estimate the actual dates by means of a simple diagram as shown in figure 1. This chart may be used for that purpose by indicating thereon for any station the mean monthly temperature for each of the two months for which the values are nearest the vegetative point (43° F.), when a straight line drawn from one point to the other will intersect the vegetative temperature line (43°) at the approximate date on which the temperature rises to that value in spring or falls below it in fall. The mean monthly temperature should be considered as the value at the middle of the month or at the point where the vertical dash line intersects the proper horizontal temperature line. Example: The mean monthly temperature at Columbus, Ohio, for March is 39° and for April, 51°. By drawing a straight line between the point where the 39° temperature line and the dotted line for March intersect, to the point where the 51° line and the middle of April coincide, it crosses the vegetative temperature

line (43°) at a point indicating approximately March 25, which represents the beginning of the vegetative period at Columbus. The chart may be used also for the fall months by reading from right to left as indicated by the arrangement of months at the bottom of the chart.

As the theoretical period of plant growth extends from the date on which the mean daily temperature in its annual march rises to 43°, to the date on which it falls below that value, it is of interest to study the relation in length between this period and that usually designated as the growing season, or the period between the spring and fall frost dates. As the average frostless period in most of the country is considerably shorter than the vegetative period, as is shown by the accompanying charts, it follows that the vegetative period is shortened by the occurrence of frost, at least in so far as vegetation that is susceptible to frost damage or destruction is concerned. Except in portions of the Florida Peninsula

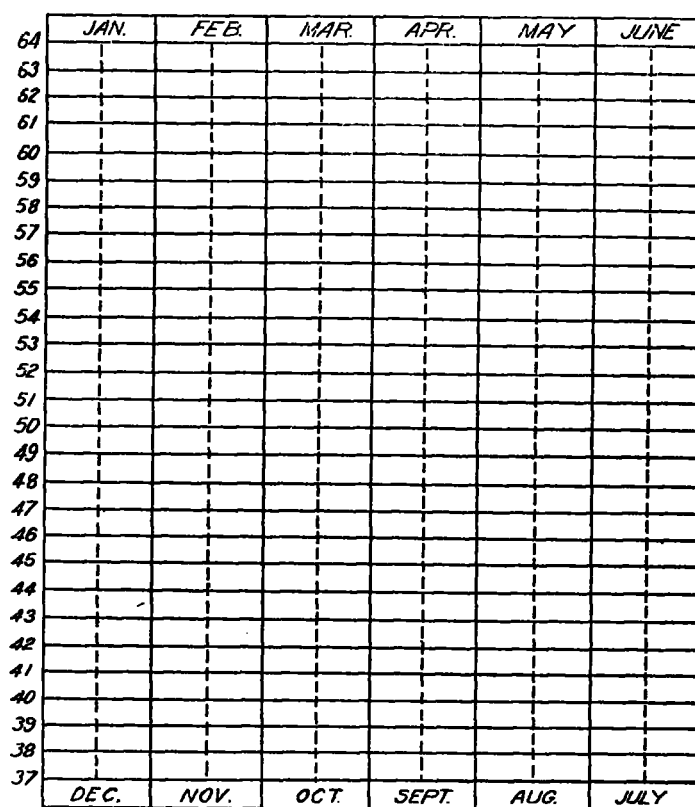


FIG. 1.--Diagram for determining vegetative temperature and frost dates from mean monthly temperatures.

and in some favored localities in California, frost occurs during each winter. The length of the period during which it may be expected varies with the latitude and altitude, especially the former, in most sections east of the Rocky Mountains. After the first killing frost in fall, frost occurs at irregular intervals until the annual spring rise in temperature reaches a certain value, when it ceases on the average until approximately that value is again reached in the fall recession of temperature. These mean daily temperature values which coincide with the cessation of frosts in spring and their resumption in fall are remarkably uniform, not only under different topographic conditions, but also over large geographic areas. Away from marine influence, they are mostly from 9° to 13° above the vegetative temperature values, as before defined.

<sup>2</sup> See Zon, Meteorological Observations in connection with botanical geography, agriculture, and forestry, MONTHLY WEATHER REVIEW, April, 1914, 42:217-223.

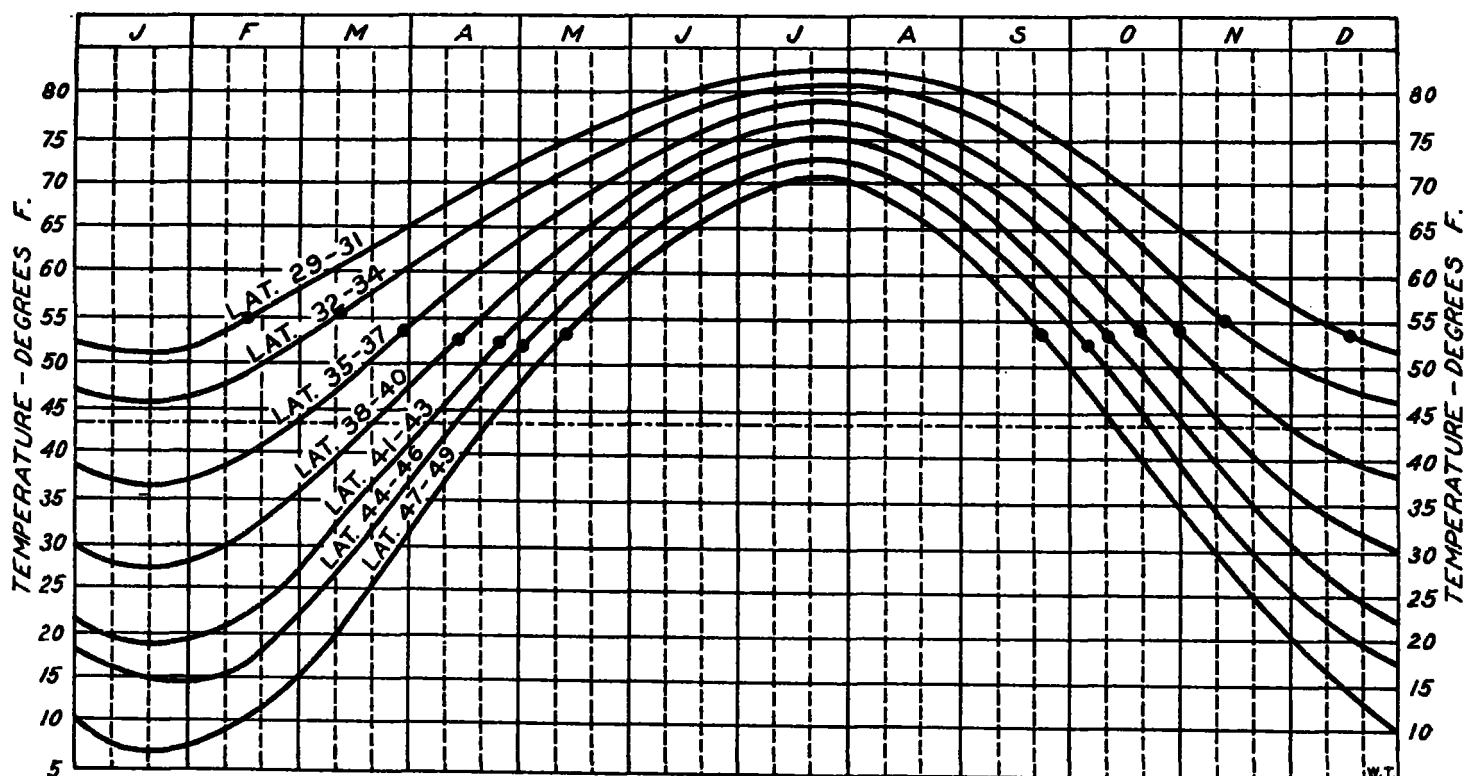


FIG. 2.—Annual march of temperature and average dates of the last killing frost in spring and the first in autumn, for successive belts of 3° latitude in width, from 29° to 49°, between the Rocky Mountains on the west and the Lake region and Appalachian Mountains on the east, based on the records of all regular Weather Bureau stations within this area, 68 in number. The belts are delineated to the nearest whole degree of latitude. Temperature —. Frost dates •.

Chart IV indicates the normal mean daily temperature on the average date of the last killing frost in spring for all of the regular Weather Bureau stations in the United States. It shows that in most of the country the average frost-free date in spring corresponds to a mean daily temperature of from 52° to 56°, except along the central and north Pacific Coast, the region of the Great Lakes, and along the middle and north Atlantic seaboard, where the temperatures are lower. Chart V shows similar data for fall frosts which are in close agreement with those of the spring chart. It will be noticed, however, that in limited areas the first fall frost occurs, on the average, while the mean daily temperature is a degree or two higher than is necessary to cause a cessation in spring frosts in an average year. Considering the records for all stations throughout the country the mean daily temperature on the average date of the last killing frost in spring is 52.1°, and on the average date of the first in fall it is 52.6°. By areas, the spring and fall averages are as follows:

	Spring.	Fall.
	° F	° F
North Atlantic States.....	48.0	50.6
South Atlantic States.....	53.3	53.8
Gulf States.....	55.7	56.0
Ohio Valley and Tennessee.....	53.2	53.1
Lake Region.....	47.6	48.9
Mississippi Valley.....	52.6	53.5
Great Plains.....	53.2	55.2

It is interesting to note the similarity of these temperatures over large areas, even extending from the northern to the southern boundaries of the country. On Chart IV, for example, there is shown a wide belt extending from the Gulf of Mexico northwestward through the Plains States to the Canadian boundary in which frost ceases

in spring, as a rule, when the temperature in its annual march rises to 54° or 55° F. The winters are long and severe in the northern portion of this belt, and the soil usually freezes to great depths, but in the extreme south very little winter is in evidence and the vegetative period extends throughout the year. Notwithstanding these great differences in winter conditions, when the normal mean daily temperature in spring rises to 55°, frost ceases, on the average, in the extreme north as well as in the south; the difference in the average time of occurrence of the last killing frost in spring along the central Gulf coast and in northern North Dakota is nearly 4 months. Attention is also invited to the comparatively low temperature values appearing along the central and northern Pacific coast, the Lake region, and the north Atlantic coast, where the water influence is felt in warding off frost. There is a similar area shown to the leeward of the central and southern Appalachian Mountains in Virginia and North Carolina where frost ceases on the average with a lower mean temperature in spring and does not occur with as high temperatures in fall as in the surrounding regions.

Owing to the fact that these temperatures corresponding to the average frost dates are so uniform, it is possible to determine very closely the average frost dates from the mean daily temperatures. In the case of cooperative and other stations for which daily values are not available the dates can be closely approximated from the mean monthly temperatures by the use of figure 1 and Charts IV and V, the charts showing for different localities the average frost temperature values. The method to be used is the same as described for finding the beginning and ending of the vegetative period, except that the frost temperature values shown on Charts IV and V must be substituted for the vegetative temperature (43°). Example: Chart IV shows that the average spring frost

temperature in the vicinity of Ithaca, N. Y., is  $52^{\circ}$ . Ithaca has a mean monthly temperature for April of  $44^{\circ}$ , and for May  $57^{\circ}$ . A straight line drawn from the proper points on the chart intersects the frost temperature line for that locality ( $52^{\circ}$ ) at approximately May 5, which indicates the average date of last killing frost in spring at that point. Fall frost dates may be found in the same manner by reading the chart from right to left, as indicated previously. By this method frost dates can be determined from cooperative or other stations that may have temperature but not reliable frost records. In addition, owing to the smaller variations in the mean monthly temperature than in the actual frost dates from

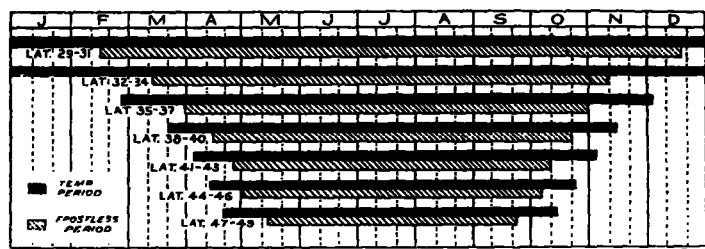


FIG. 3.—Average period of the year with mean daily temperature  $43^{\circ}$  or above and the average frostless period (from the average date of the last killing frost in spring to the first in autumn) for the same latitudinal belts used and explained in Fig. 2.

year to year, the average frost dates for short record stations can often be determined more accurately from the mean temperature than from the frost records themselves; that is, the average date that would be obtained if longer records were available. For example, the

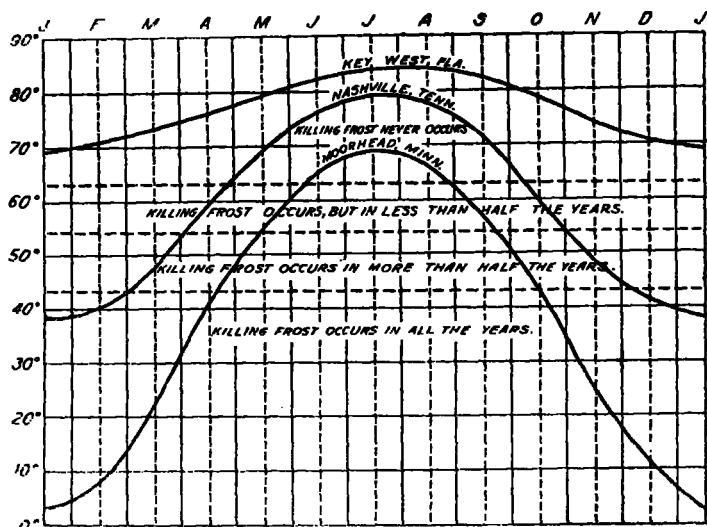


FIG. 4.—Relation of mean daily temperature to the occurrence of killing frost.

average date of the first killing frost in fall at Washington, D. C., based on a 45-year record, 1874 to 1918, is October 22. If we divide this into nine 5-year periods and determine the average frost date for each of these by the temperature method described, the result in no case differs from the 45-year mean by more than four days, while the actual averages computed from the recorded frost dates for the respective periods vary from October 16 to November 2. Again, if only the 5-year record from 1914 to 1918 were available for Washington, the recorded dates of last killing frost in spring would give the average date as March 29, but the mean temperature for this period gives an indication of April 7 as the average date,

when determined as indicated. The 45-year average is April 8.

A picture of the relation of frost occurrence to mean temperatures is afforded by figure 4. This graph shows that, broadly speaking, the following general law is applicable, the temperature values differing only slightly for different localities and for the spring and fall seasons. Killing frost occurs each year in spring until the normal mean daily temperature rises to approximately  $43^{\circ}$  (the vegetative value). After this temperature is reached, frost does not occur in all the years, but does occur in more than half the years until the average temperature reaches  $54^{\circ}$ , which corresponds in date to the average occurrence of the last frost in spring. Thereafter killing frost may be expected with less frequency, or in less than half the years, until the mean daily temperature rises to approxi-

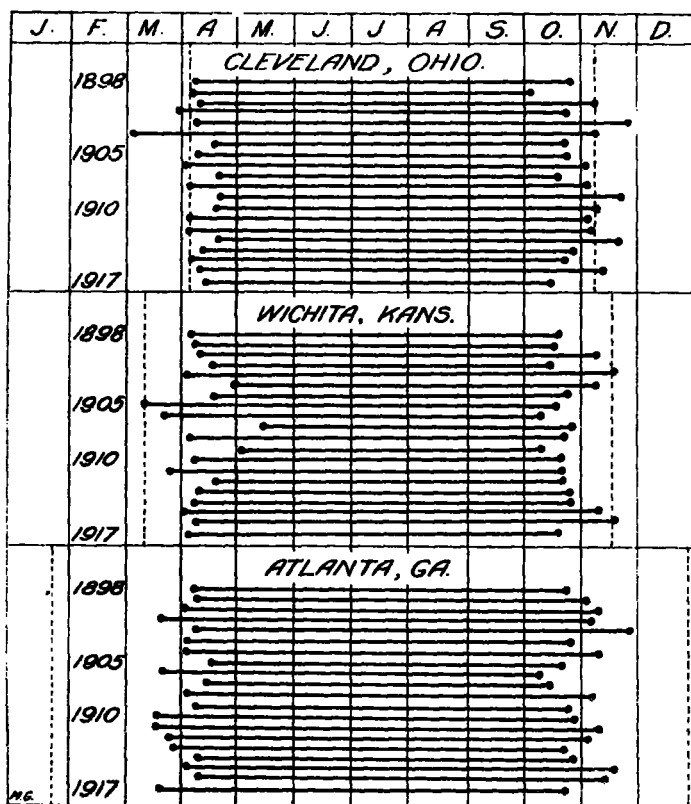


FIG. 5.—Variations of the frostless period from the vegetative period for each of the 30 years from 1898 to 1917, inclusive, at selected stations, representing regions of small, moderate, and large variations. The dots represent the dates of the last killing frost in spring and the first in fall, and the lines connecting the dots show the length of the frostless season for the respective years. The dates on which the vegetative period is reached in spring and passed in fall are shown by the vertical dash lines.

mately  $63^{\circ}$ , after which it is not experienced. This holds good also for fall frost.

Figure 2 shows the annual march of temperature and the average dates of the last killing frost in spring and the first in fall for successive belts three degrees of latitude in width, from latitude  $29^{\circ}$  to  $49^{\circ}$ , between the Rocky Mountains on the west and the Lake region and the Appalachian Mountains on the east, based on the records of 68 regular Weather Bureau stations within this area. The curved lines show the annual march of temperature for the respective belts, based on the average of all records within each belt, which is considered to the nearest whole degree of latitude, and the dots indicate the average frost dates. A horizontal dash line has been drawn to show the vegetative temperature value ( $43^{\circ}$ ). It will be seen that the frost dots are disposed horizontally



in an orderly arrangement and are considerably higher than the vegetative temperature line. In figure 3 the average length of the potential growth, or vegetative, period is compared with the average frostless period for the same belts that were used in the construction of figure 2. This shows graphically for the several belts the effect of killing frost in shortening the potential vegetative period in so far as plants that are susceptible to frost damage or destruction are concerned.

Charts VI and VII show, respectively, the average number of days by which the potential growing season is shortened in spring and in fall by frost. Chart VI indicates the average number of days in spring after the vegetative temperature period is reached until the average date of the last killing frost, while Chart VII shows the average number of days the first killing frost in fall occurs before the mean daily temperature falls below the vegetative value. It will be noted that the spring and fall charts correspond to a remarkable degree.

Chart VIII shows the total number of days that the average frostless season is shorter than the vegetative period. It indicates that the only locality in which the frostless season is longer than the vegetative period is comprised in a small area along the North Pacific coast. In most of Washington, portions of upper Michigan, and much of Minnesota, as well as along the North Atlantic seaboard, killing frost shortens the vegetative period by less than 20 days, but in much of the central portion of the country the difference in the two periods ranges from 40 to 60 days. From Virginia, Kentucky, Missouri, and Oklahoma southward this difference increases rapidly from 60 to more than 100 days in the northern portions of the Gulf States. Southward from the upper Missis-

sippi Valley to southern Arkansas the difference increases from 20 to 100 days, or from less than one to more than 3 months.

Figure 5 shows for Cleveland, Ohio; Wichita, Kans.; and Atlanta, Ga., representing, respectively, regions of small, moderate, and large variations, the relation of the frostless season to the vegetative period for each of the 20 years from 1898 to 1917, inclusive. The dots represent the dates of the last killing frost in spring and the first in fall and the horizontal lines connecting the dots show the length of the frostless season for each year. The average dates on which the vegetative period is reached in spring and passed in fall are shown by the vertical dash lines.

This graph permits an interesting comparison between conditions existing in the vicinity of Cleveland and those near Atlanta. In the former locality the average frost dates agree closely with the vegetative temperature dates, and consequently the potential growing season is not materially shortened by the occurrence of frost. Protection of truck crops from frost in this locality, therefore, would be of less value in lengthening the growing season than farther south. In the vicinity of Atlanta, however, the vegetative period is much longer than the frostless period, and consequently hardy vegetation, such as winter grains and grasses, has a much longer growing season than has vegetation susceptible to frost damage. It follows that frost protection can be much more profitably practiced in northern Georgia than in northern Ohio. South of Atlanta, the mean daily temperatures remain above the vegetative value throughout the year, which makes an even greater contrast between the potential vegetative and frostless seasons.

#### WEATHER CONTROL OF THE PERIODICAL CICADA.

By WILLIS E. HURD.

[Dated: Weather Bureau, Washington, D. C., Mar. 29, 1919.]

Mr. Dixon Merritt characterizes the periodical cicada, more popularly known as the 13-year or the 17-year locust, as "the most interesting insect in the world."<sup>1</sup> This interest must lie in the fact of its peculiar life history, particularly its long period of hibernation at a depth of 6 to 24 inches, or sometimes more, under the surface of the ground, and also more or less in its somewhat thrilling musical habits during the few days allowed it in which to dwell amongst the haunts of men.

Comparatively little data have been collected concerning the weather control of this insect, but sufficient information is at hand to permit of some generalizations as well as theories on the subject. The 17-year cicada is largely an inhabitant of the northern States, while its 13-year relative is quite as exclusively confined to the South. Since these insects are physically identical, except in one or two minute particulars, it was very reasonably suggested that the southern type probably emerges from the nymph state four years the earlier only because of the more favoring climate, since the warmer the weather in general the more is the development of the individual facilitated. However, there are no intermediate zones of development graduating from one of a 13-year period along the southern borders of the Gulf States, to another of a 17-year period along the Canadian border, and the two brood types do not change the length of their hibernation periods, except for slight individual and local diversions, even in the median regions where they overlap. As early as 1881 and 1885

Prof. Riley made experiments<sup>2</sup> with the two varieties to determine whether each, if transplanted from the outer extreme of its own to that of the other's habitat, would change its date of emergence to conform to that of the other under the widely differing climatic influences. When the times of emergence arrived, trained observers kept watch of the areas where the little colonies had been transplanted, but unfortunately they obtained no positive results upon which to base definite conclusions. So far as weather or climatic control of the cicada is concerned, however, the following concrete rules may be accepted:

With climatic conditions normal, broods will appear according to scheduled time.

With climatic conditions abnormally warm or cold during the period of hibernation the broods may appear a few days earlier or later than the scheduled time.

In addition, cool weather intervening while the broods are emerging will cause a delay in the appearance of those not already arrived.<sup>3</sup>

The southernmost members of a brood will sometimes appear from a few days to three or four weeks in advance of the northernmost, depending upon temperature conditions.

Some interesting instances of accelerated emergence have been observed. At Belvidere, Ill.,<sup>4</sup> an old apple orchard, in which a swarm of cicadas had lived in 1888, was grubbed up a few years later and the ground covered

<sup>1</sup> The "17-Year Locust" in 1919. U. S. Dept. of Agr. Circ. 127, p. 3.

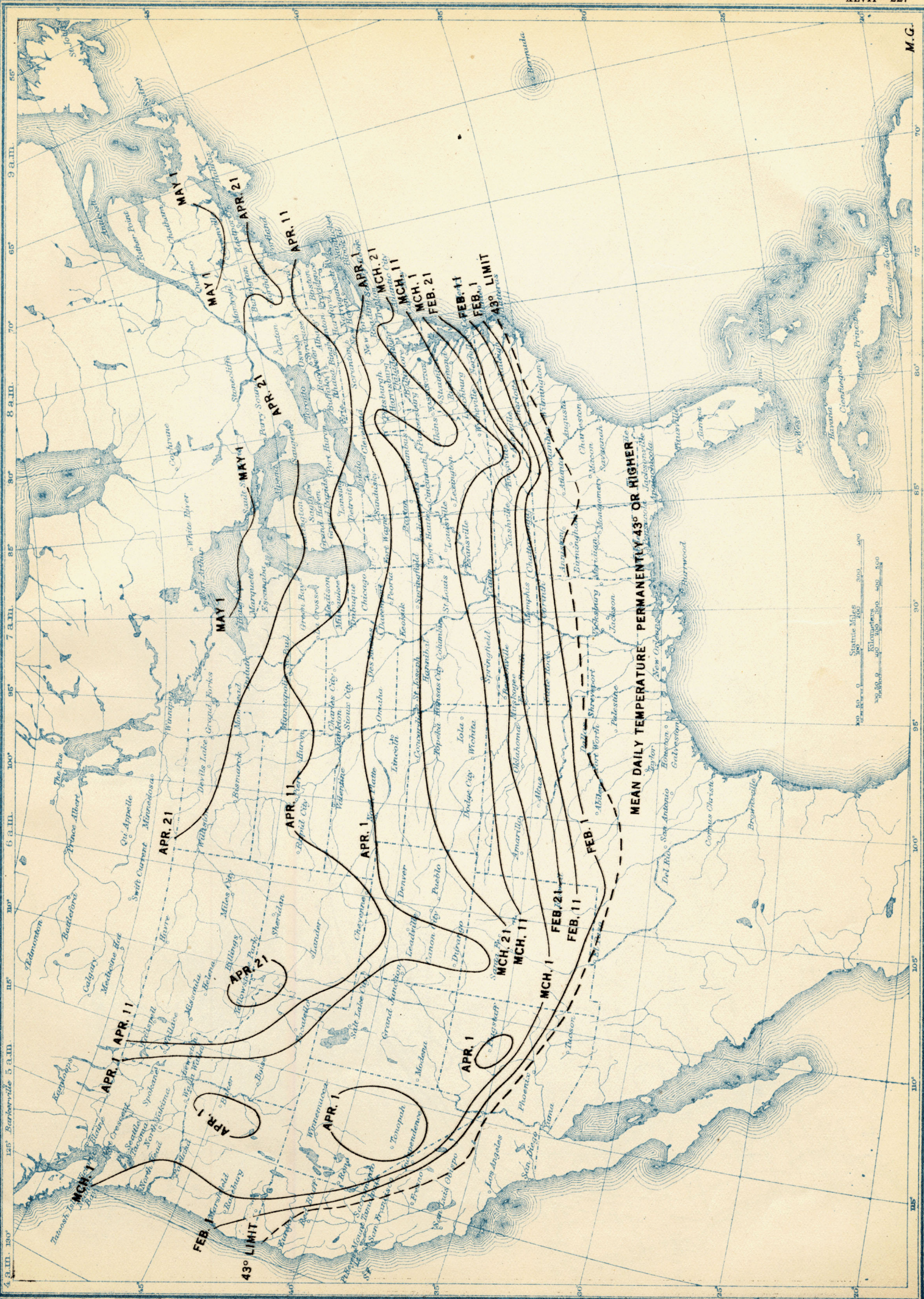
<sup>2</sup> The Periodical Cicada. C. L. Marlatt. Bur. of Ent. Bul. No. 71, pp. 18-20, 1907.

<sup>3</sup> Ibid., p. 90.

<sup>4</sup> Ibid., p. 24.

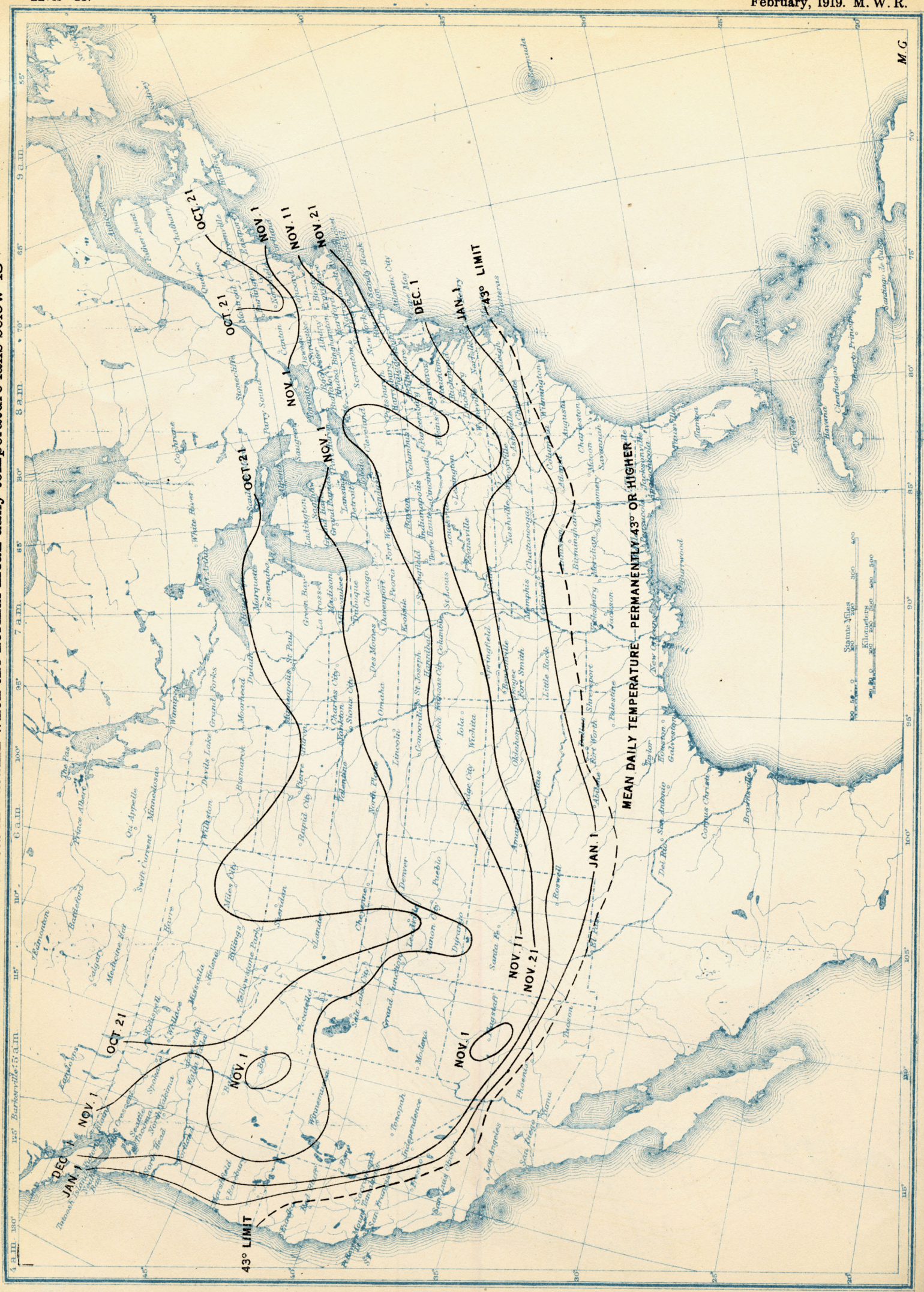


J. B. K. Chart I. Dates in spring when the normal mean daily temperature rises to 43°.





J. B. K. Chart II. Dates in autumn when the normal mean daily temperature falls below 43°





J. B. K. Chart III. Average annual number of days with mean temperature 43° or higher.





J. B. K. Chart IV. Normal mean daily temperature on average date of the last killing frost in spring.





J. B. K. Chart V. Normal mean daily temperature on the average date of the first killing frost in fall.





J. B. K. Chart VI. Number of days in spring, after the normal mean daily temperature rises to 43°, until the average date of the last killing frost.





J. B. K. Chart VII. Number of days in autumn, after the average date of the first killing frost, until the normal mean daily temperature falls below 43°.





J. B. K. Chart VIII. Number of days the average frostless period is shorter than the average vegetative period.

